Technology Development and Infusion by NASA's Entry Systems Modeling Project

Michael Barnhardt, Aaron Brandis
Michael Wright, Monica Hughes

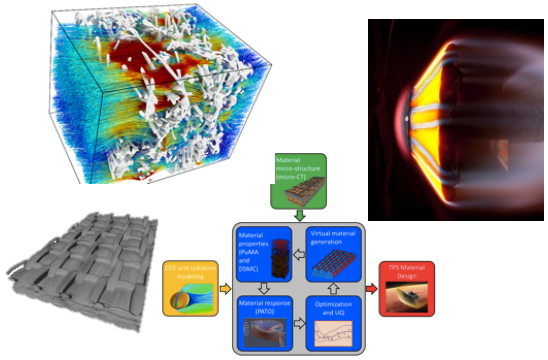
2019 FAR Conference | October 1, 2019

Entry Systems Modeling Project (ESM)

Core Investment Areas

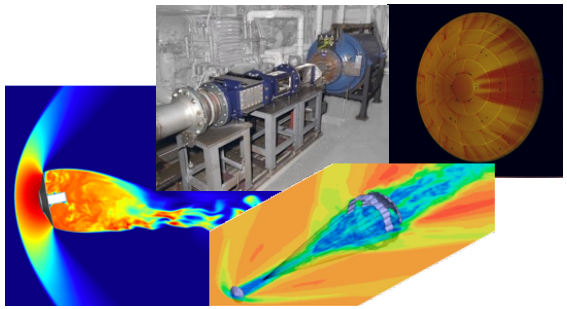
Predictive Materials Modeling

Advanced models for PICA, Avcoat and woven TPS; Micro- to engineering-scale analysis tools; Detailed material characterization and model validation



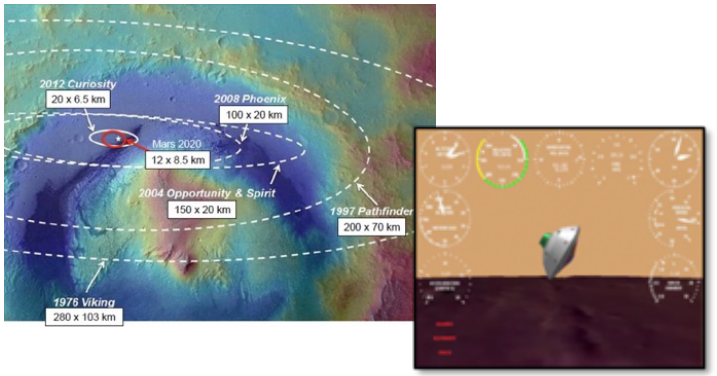
Aerosciences

Parachute dynamics; Free-flight CFD; Magnetic suspension wind tunnels; Experimental validation; Roughness, Advanced computational methods



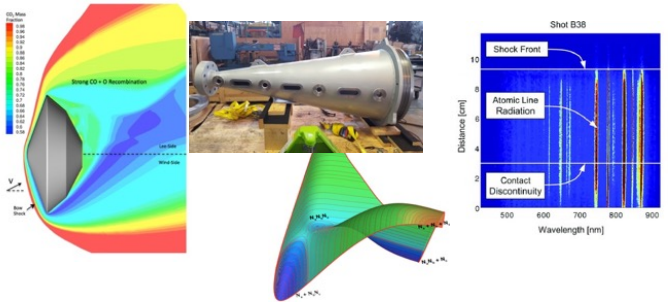
Guidance, Navigation, and Control

Entry guidance methods to enable precision landing of large robotic and human Mars missions



Shock Layer Kinetics and Radiation

Radiation databases and models for Earth entry and other destinations of interest; High-fidelity coupled analysis tools



Orion & Mars 2020 Margin Policies

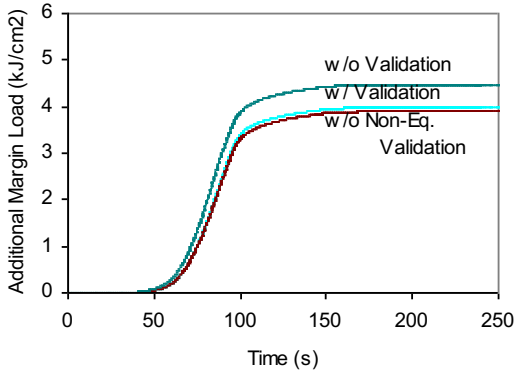
Radiative Heating

- **ESM and other projects have done a tremendous amount of work generating data for validation of aerothermodynamic models**
- **ESM developed a rigorous uncertainty model for radiative heating, quantifying individual contributions from variety of phenomena and applying Bayesian statistics**

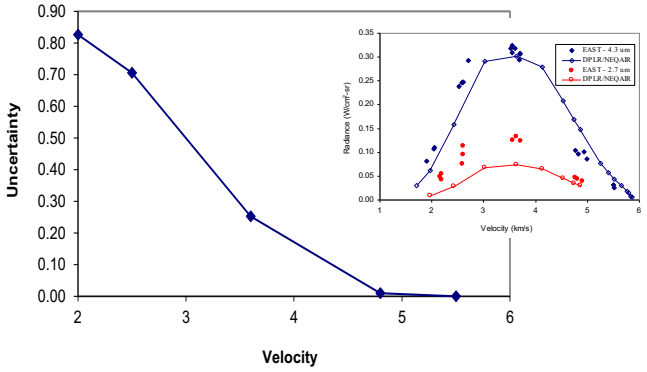
> ***"Development of a Radiative Heating Margin Policy for Lunar Return Missions"***
> Brett Cruden, Aaron Brandis, Christopher Johnston
> Journal of Thermophysics and Heat Transfer, 2018

- **The process was applied to Orion and Mars 2020 radiative environments to update their margin policy**
  - Orion margin decreased from 53% to 42%
  - Mars 2020
    - Forebody margin decreased from 50% to 36%
    - Aftbody margin decreased from 67% to 47%
  - *Negative margins were eliminated, preventing re-design*

Margined heat load over direct lunar entry trajectory



Radiance uncertainty vs. velocity during Mars entry

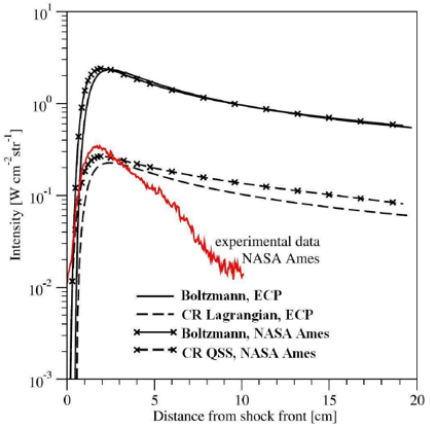


Modeling Entry at Titan

Post-Huygens analysis motivated community to generate data to support Titan radiation models

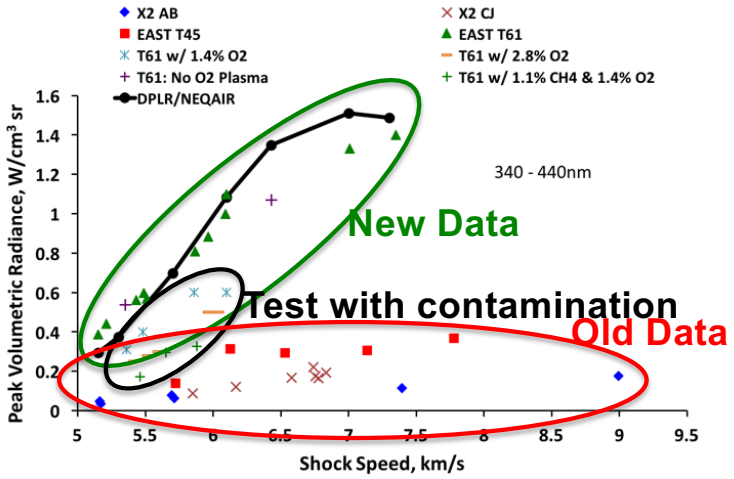
- **Experiments suggested much lower radiation than earlier models but suspicion arose concerning quality of data**
- **Anticipating new Titan mission proposals, in 2017 ESM conducted a new investigation of Titan radiation in the improved Electric Arc Shock Tube**
- **Investigation found that contamination and other test defects likely explain poor agreement between models and earlier experiments**
- **New data are in excellent agreement with models and provide much greater confidence in Titan aerothermal predictions for the Dragonfly mission**

"Titan Atmospheric Entry Radiative Heating"
Aaron Brandis, Brett Cruden
AIAA Paper 2017-4534



Left: Collisional-radiative models could be tuned to match peak intensity but failed to capture observed decay rate.

Below: New data are in excellent agreement with state-of-the-art models across range of Titan entry speeds.

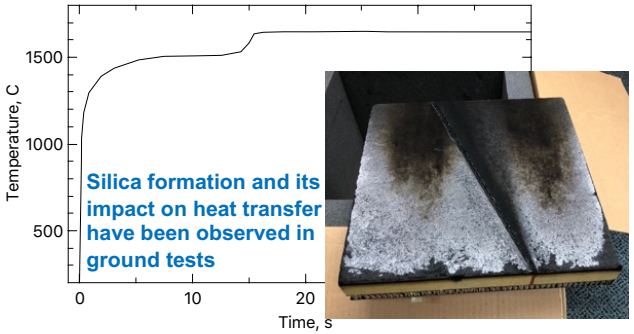


PICA-NuSil

Mars Science Laboratory and Mars 2020

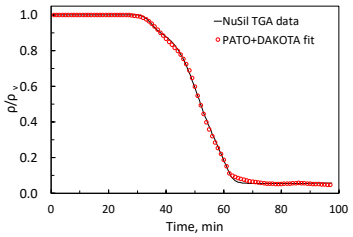
Silicone (NuSil) coating on MSL and Mars 2020 significantly impacts our interpretation of flight measurements

- **Silica coating acts as an oxidation barrier**
- **It could also impair the transport of pyrolysis gas into boundary layer**
- **Modeling ablation of PICA-NuSil system is crucial to quantifying accuracy for post-flight reconstruction of flight instrumentation**

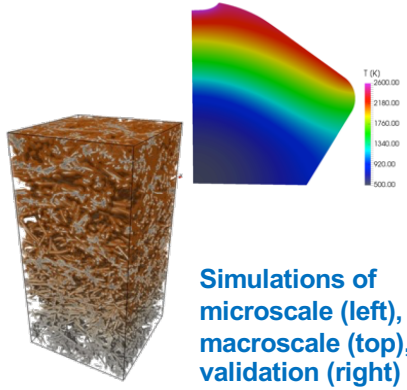


Development of High-fidelity Model

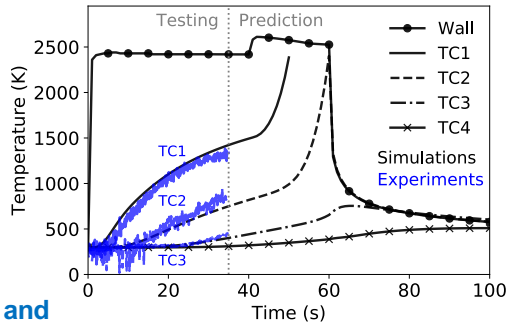
- **PICA-NuSil material properties data** ***(Brody Bessire, NASA Ames)***
- **Finite-rate gas/surface interaction data** ***(Tim Minton, Montana State University)***
- **Building out micro- and macro-scale simulation capabilities** ***(Nagi Mansour, NASA Ames)***



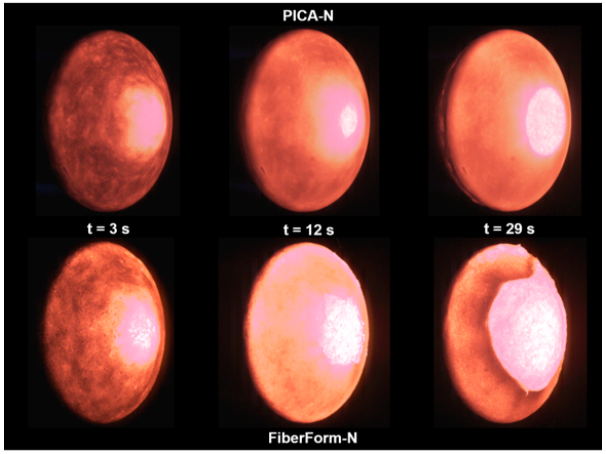
Material property measurements



Simulations of microscale (left), macroscale (top), and validation (right)



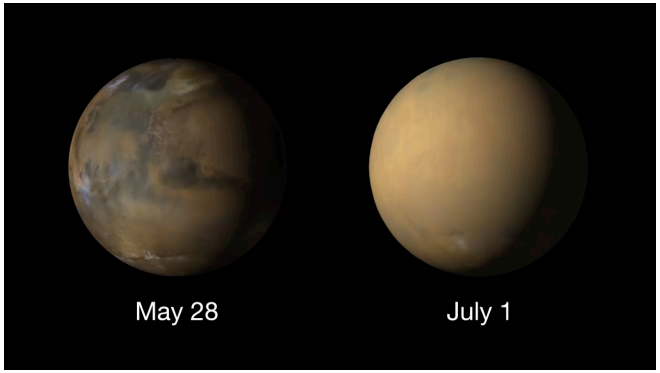
Ground Test Validation



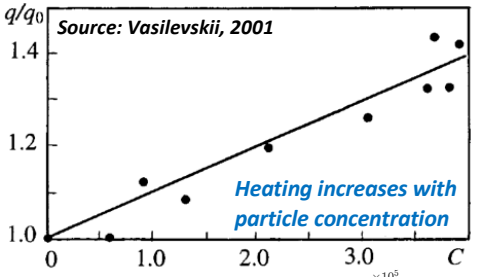
Aerothermal-mechanical Erosion of TPS Due to Dust

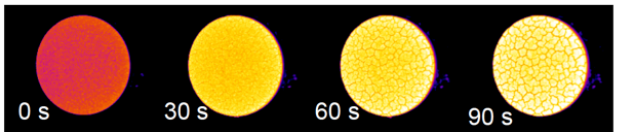
- **Martian dust storms can augment TPS recession through mechanical erosion and greater heating. Global dust storms have been observed to occur every few years without warning.**

- **State of the art traces back to mid-90s studies for Mars Pathfinder**
  - Phenomenological models of erosion based on scant experimental data
- **Risks carried for Mars InSight and ExoMars Schiaparelli**
- **ESM leads broad collaboration**
  - German Aerospace Center (DLR) providing critical and unique experiments to guide modeling
  - Stanford University
  - University of Minnesota
  - Missouri University S&T

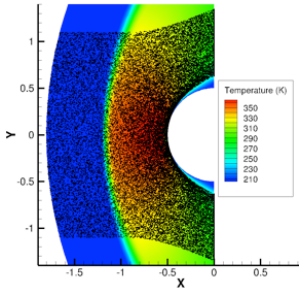


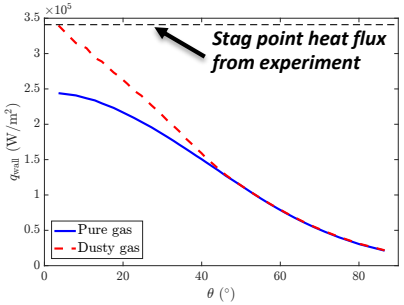
In 2018, Mars Reconnaissance Orbiter detected a sudden growth of dust suspended in the atmosphere. Within a month, the entire planet was shrouded. InSight would land only 4 months later.





Observed erosion patterns due to particle-laden flow
Source: Ali Guelhan, DLR





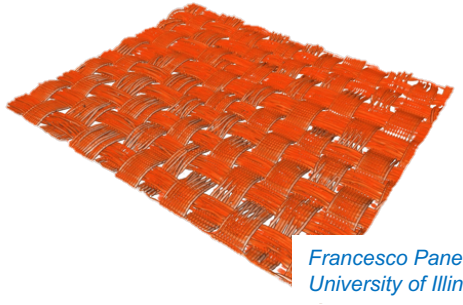
Advanced modeling under development by ESM and partners is providing first quantifiable estimates of phenomenon and our ability to predict it.

Parachutes for Entry Systems

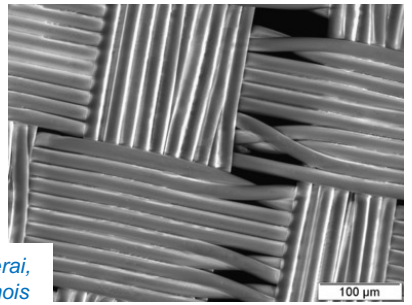
Parachute performance has been a concern of several programs in recent years

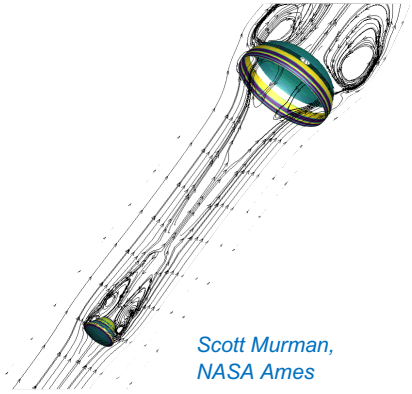
ESM and its partners have pioneered new capabilities

- Microscale fabric structure and degradation (Mars InSight)
- Off-nominal descent dynamics (Orion and Commercial Crew)
- Inflation stress and failure (Mars 2020 and Commercial Crew)

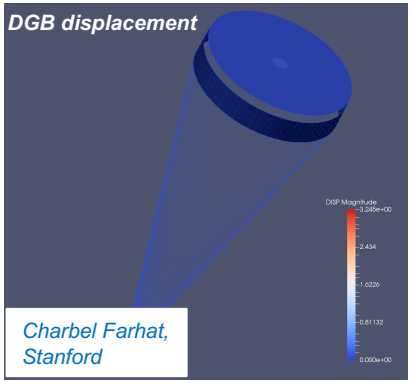


Francesco Panerai, University of Illinois

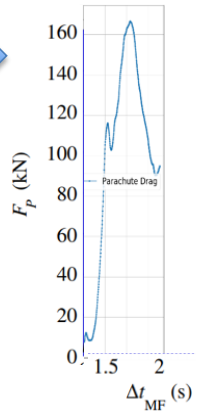




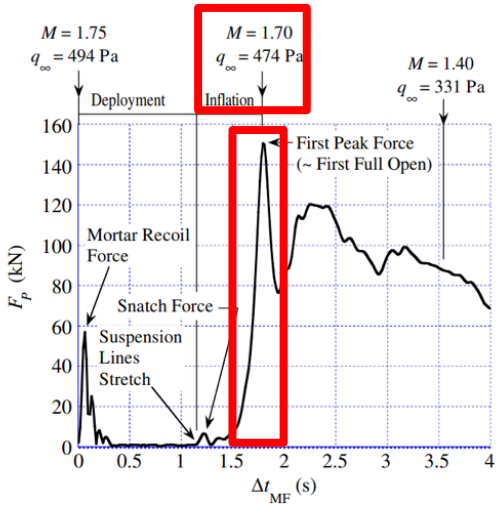
Scott Murman, NASA Ames



Charbel Farhat, Stanford



Stanford AERO Code



Test Data

Parachutes a noted concern for ESA ExoMars 2020 as well
https://spacenews.com/esa-turns-to-nasa-to-assist-in-crucial-exomars-parachute-tests/

Closing Thoughts

Mission reliance on modeling and simulation capability continues to grow

At the same time, there are many challenges that the state of the art is not quite ready to tackle

- **Looking ahead: Mars Sample Return, human Mars exploration, and high-reliability**

Investment in cross-cutting capability development can deliver results – on time and on budget

- **The key is tight collaboration with stakeholders to balance resource constraints with schedule requirements**
- **The Entry Systems Modeling Project has partnerships across all NASA mission directorates, US Departments of Defense and Energy, and several international organizations**

Thank you for your time!